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(54) Electrohydraulic brake system for a road vehicle

(57) An electrohydraulic multi-circuit system for a road vehicle comprises, for each wheel brake, a hydraulic servocylinder 16 to 19 driven by an electric motor. For normal braking, pedal actuation switches valves 38, 39 to a blocking position and valve 54 to a through-flow position, cylinders 16-19 are driven by their motors, unit 21 with a single-circuit master cylinder 31 serves as a desired-value transmitter, and fluid from the master cylinder passes into a storage element 52 which acts to provide pedal "feel". In the event of failure of the vehicle's electronic system, brake pressure is delivered from the master cylinder to the front-wheel brakes. The master cylinder includes a central valve 94 which remains open during normal braking and which is closed, due to increased pedal travel, on failure of the electronic system.

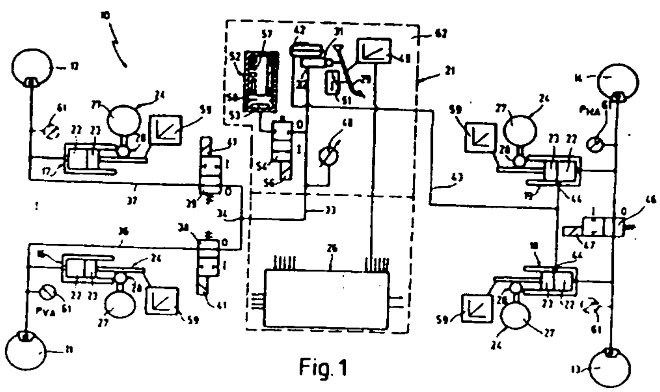

Fig.1

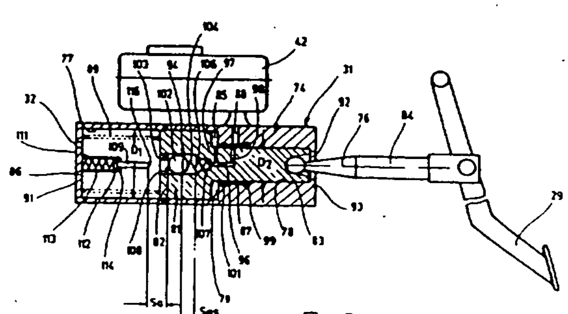

Fig. 3a

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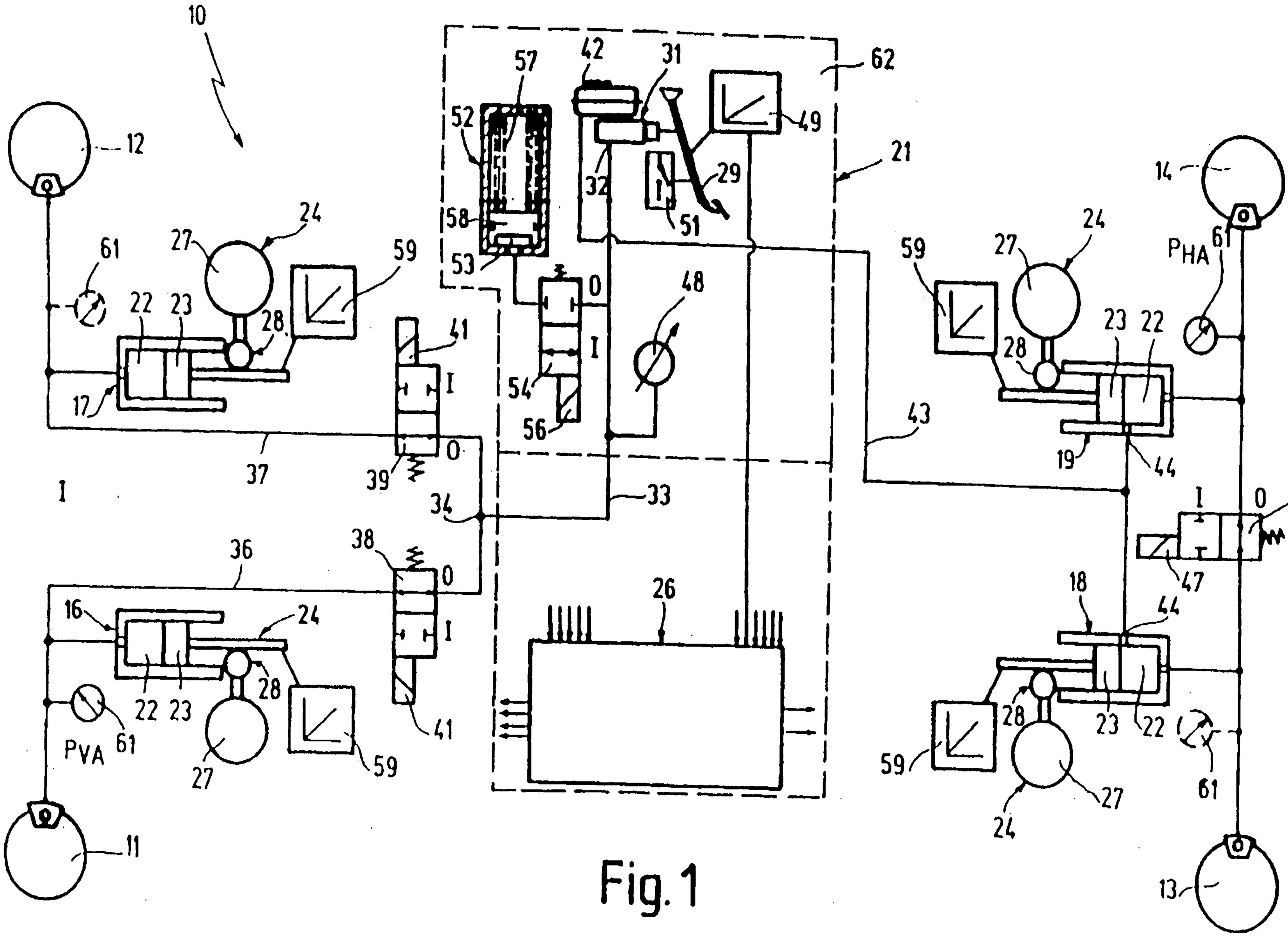
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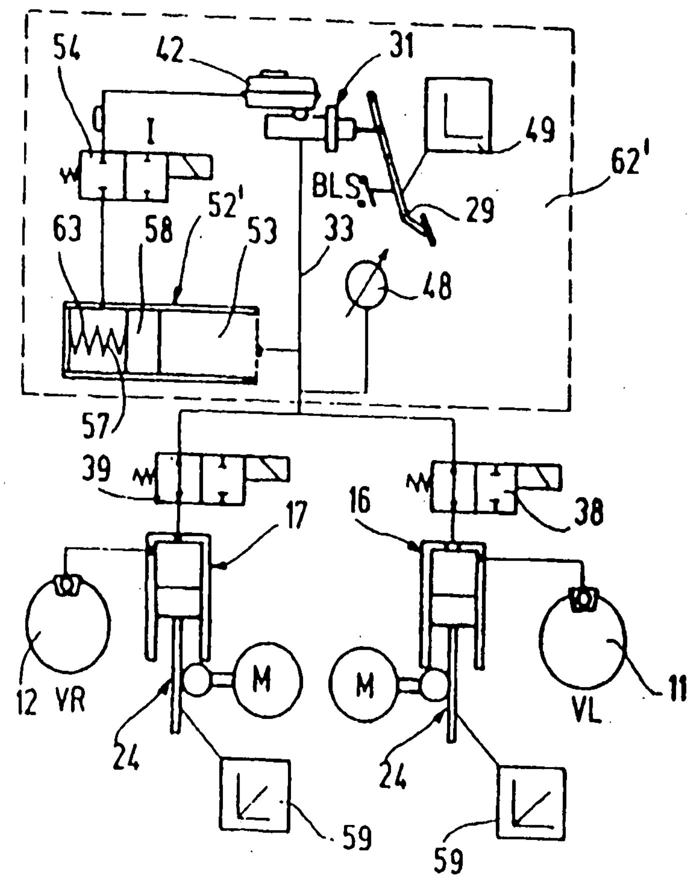
Fig. 1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38
12 VR
M
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Fig. 2a

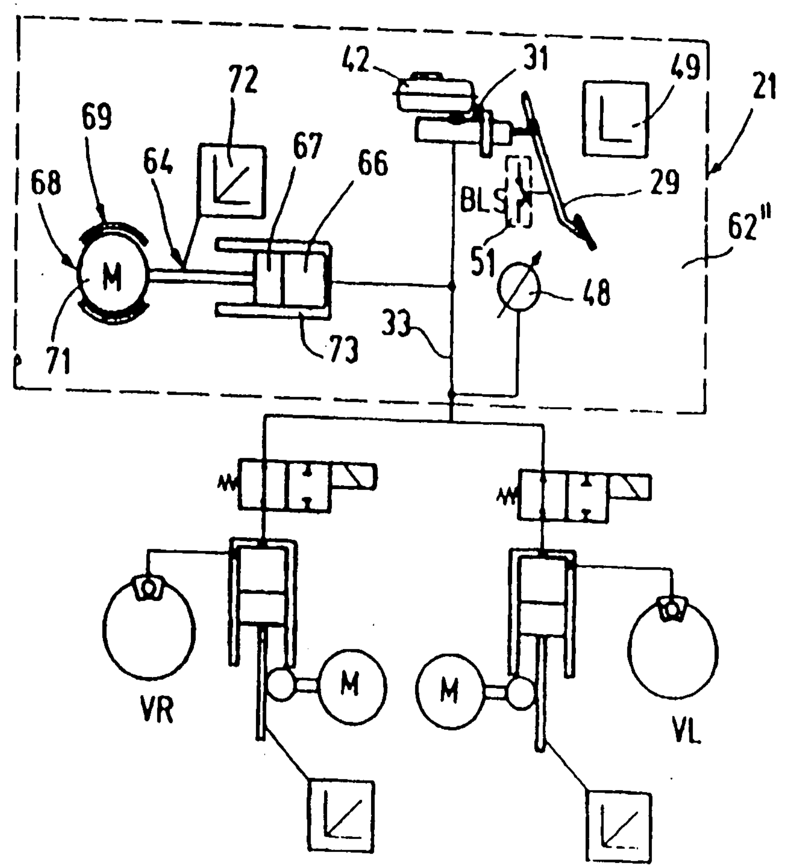
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Fig. 2b

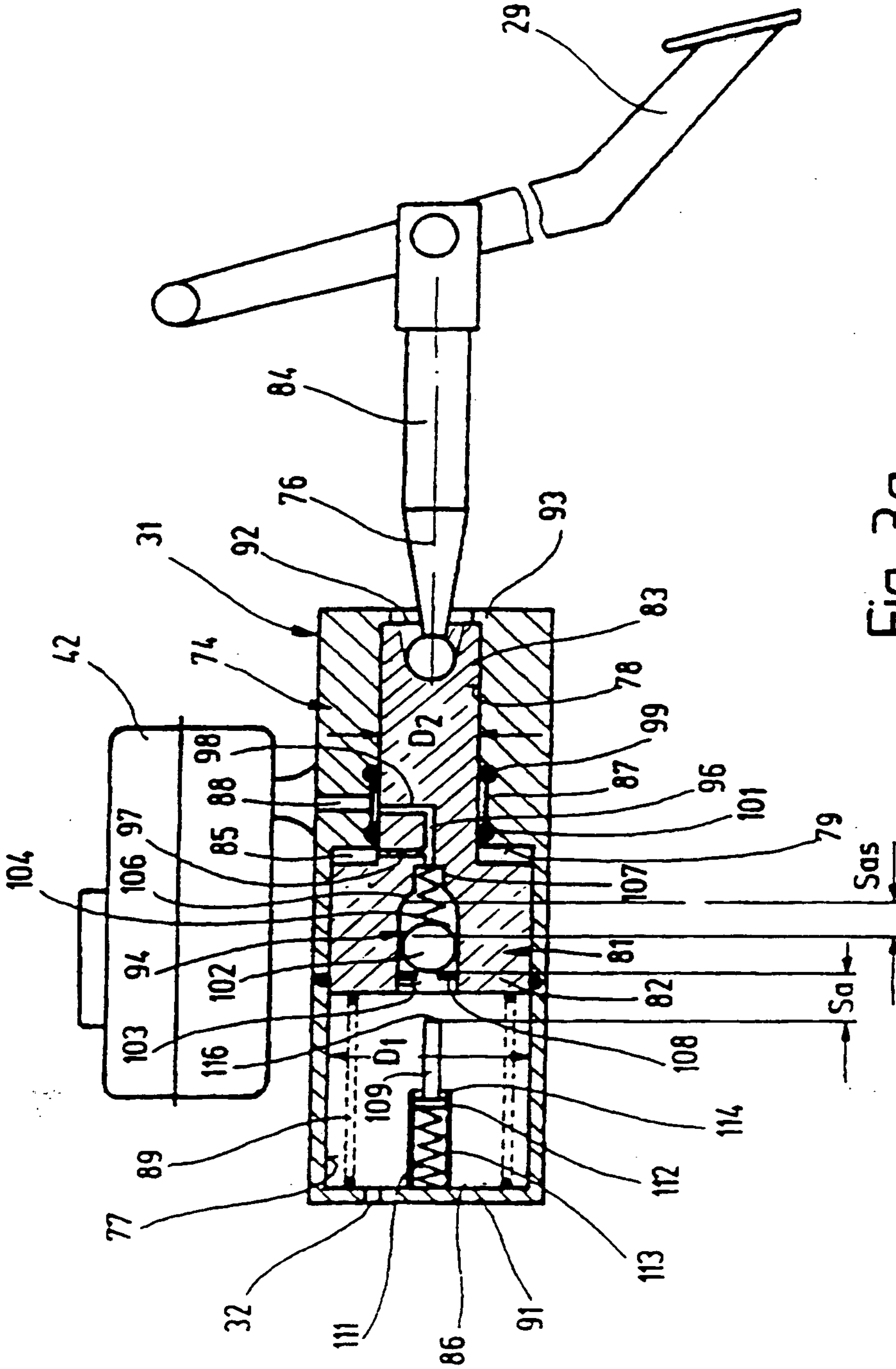
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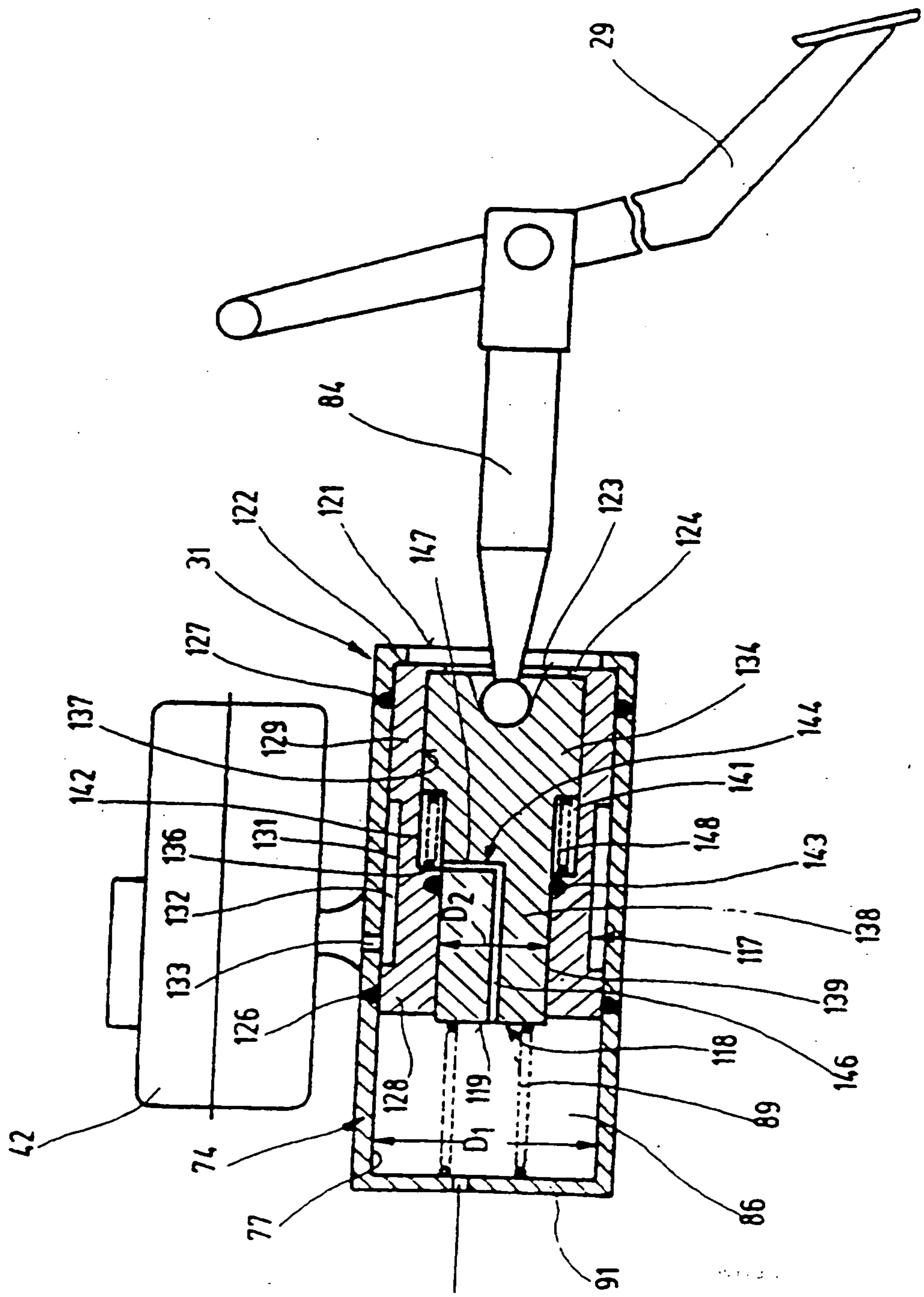
Fig. 3a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D1
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77
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Fig. 3b

Brake-pressure control system for an electrohydraulic multi-circuit vehicle brake system

The invention relates to a brake-pressure control system for a road vehicle with electrohydraulic multi-circuit brake apparatus, which:

a) comprises hydraulic servo-cylinders which are individually assigned to the wheel brakes, can be driven by electric motor and permit, in one stroke of their piston, the maximum brake pressure in the connected wheel brake for which the said brake is designed to be increased and decreased and, under the control of the output signals of an electronic control unit, enable at least the following functions to be implemented:

a1) normal braking mode in accordance with desired-value signals which can be triggered by the driver by means of a desired-value setting unit and are characteristic of the anticipated value of the deceleration of the vehicle, including control of the front-axle/rear-axle braking force distribution (EBKV);

a2) anti-lock braking control by means of automatic brake pressure modulation (ABS function);

a3) traction control (TCS function) by means of automatic activation of the wheel brake of the vehicle wheel which is respectively tending to slip;

a4) vehicle movement control (VMC) by means of automatically controlled increase in brake slip at one or more of the wheels of the vehicle,

b) the desired-value setting unit comprising a single-circuit master cylinder to whose output pressure space the front-wheel brakes are connected by means of in each case one change-over valve which is constructed as a 2-position solenoid valve and in whose blocking functional position, which is assumed when its switching magnets are excited, the front-wheel brakes are blocked off from the single-circuit master cylinder

and in whose flow position, which is assumed as normal position, brake fluid can be displaced directly into the front-wheel brakes by activating the master cylinder. Such a brake control system will hereinafter be referred to as "of the type referred to".

Such a brake-pressure control system has been disclosed by DE 43 35 769 C1.

This known brake-pressure control system comprises hydraulic servo-cylinders which are individually assigned to the wheel brakes, can be driven by electric motor and permit, in a single stroke of their piston, the maximum brake pressure in the connected wheel brake for which the said brake is designed to be increased and decreased and, under the control of the electronic output signals of an electronic control unit, enable at least the following functions to be implemented:

- control of the normal braking mode in accordance with desired-value signals which can be generated by the driver by means of a desired-value setting unit which can be activated by him and are characteristic of the anticipated value of the deceleration of the vehicle, including control of the front-axle/rear-axle braking force distribution;
- if appropriate, automatic triggering of full braking if the activation behaviour of the driver, which can be detected from a chronological processing of sensor output signals of the desired-value setting unit, signals his desire for high deceleration of the vehicle;
- anti-lock braking control by means of automatically controlled brake-pressure modulation, and
- traction control by means of automatic activation of the wheel brake, in each case of the vehicle wheel which tends to spin;
- vehicle movement control by means of automatically controlled increase in brake slip at one or more of the wheels of the vehicle and, if appropriate, also:-

- a vehicle spacing control for backed-up traffic by means of automatic activation of the brake system as a function of output signals of a sensor system which detects the distance from a vehicle which is travelling in front.

The desired-value setting unit comprises a static single-circuit master cylinder which can be activated directly by means of a customary brake pedal, i.e. without intermediate connection of a brake booster, and to whose output pressure space the front-wheel brakes are connected via in each case one change-over valve which is constructed as a 2/2-way solenoid valve, the switched position of which valves, which is assumed when their switching magnets are excited, being a blocking position in which the front-wheel brakes are blocked off from the output pressure space of the single-circuit master cylinder and in whose flow position, which is assumed as normal position, brake fluid can be displaced directly into the front-wheel brakes by activating the master cylinder, so that, in the event of a failure of the electrical system of the vehicle, an emergency braking mode is possible by activating the front-wheel brakes, by means of which emergency braking mode a relatively high deceleration of the vehicle of up to 0.4 g ($g = 9.81\ ms^{-2}$), which is higher than the legally required minimum deceleration, can still be achieved.

So that, with the known brake-pressure control device, a pedal travel/braking force characteristic of the brake-pressure control device which is favourable, in terms of ergonomic criteria, for the possibility of metering well the brake pressure generating procedure which is to be initiated by the driver in the case of normal braking can be achieved, the feeding of brake fluid into the wheel brake cylinders takes place during normal braking as a result of the combined effect of the master cylinder and of the brake-pressure servo-cylinders, for example by virtue of the fact that the actuation travel of the pistons of these servo-cylinders for whose monitoring position transmitters which

are individually assigned to the servo-cylinders are provided is adjusted in accordance with the actuation travel of the piston of the master cylinder which can also be detected by means of a pedal-position sensor, a defined ratio of the quantity of brake fluid which is fed into the front-wheel brakes by means of the master cylinder to the quantity of brake fluid which can be fed into the front-wheel brakes by means of the servo-cylinders being obtained. In the possible situations of automatic activation of the front-wheel brakes which takes place for the purpose of the methods of adjustment and control mentioned above, the said brakes are blocked off from the master brake cylinder by means of actuation of the change-over valves, after which the brake-pressure control takes place solely by means of actuation, appropriate for control, of the brake-pressure servo-cylinders both of the front-wheel brakes and of the rear-wheel brakes of the vehicle, at the said rear-wheel brakes also in the case of normal braking.

This function of the known brake-pressure control device has the effect that, when the anti-lock braking control responds, the pedal reaction which is intended, as it were, to provide the driver with the acknowledgement of the functional state of the brake system, changes drastically, since the brake pedal becomes, as it were, hard - can no longer be moved on - and the further metering of the brake pressure which is used for building up the brake pressure again is made difficult. This is disadvantageous in particular if the braking takes place on a section of roadway with a very low coefficient of adhesion between the roadway and the wheels of the vehicle, since, under this condition, a particularly short pedal travel results, i.e. a sudden change in the pedal reaction which suggests to the driver, in none too seldom cases, the impression of a defect in the brake system, i.e. can give rise to a distraction from which incorrect driving behaviour, and thus a potentially hazardous situation, may result. Brake activation situations which are similarly capable of

misinterpretation and, moreover, also adversely affect comfortable operation of the brake system may arise if the driver wishes to brake himself during a vehicle-movement or vehicle-spacing control phase and, when doing so, is initially confronted with a "hard" brake pedal since the change-over valves are still closed. The same applies correspondingly to the case in which the vehicle is equipped with a front-axle drive and the driver wishes to initiate braking in the course of a traction control phase during which the change-over valves of the front-wheel brakes are likewise closed.

In addition, the maximum capacity of the output pressure spaces of the servo-cylinders of the front-wheel brakes must be greater than the maximum capacity of the connected wheel brakes so that, starting from a normal position of the servo-cylinder pistons in which the volume of the servo-cylinder output pressure spaces corresponds to the maximum absorption volume of the connected wheel brakes, in the event of anti-lock braking control only starting at a very high brake pressure, complete elimination of the brake pressure is nonetheless possible, which, in this respect, requires an increased overall length of the servo-cylinders of the front-wheel brakes.

A brake system with electric braking-force actuators can also be found in DE 34 10 006 A1. Furthermore, this brake system also has a master brake cylinder which applies brake pressure to hydraulic wheel brake cylinders of the front axle, the hydraulic generation of brake pressure being configured as a fallback level. The electric braking-force actuators are regulated by a control device which, for this purpose, is fed a signal relating to the activation of the brake pedal and signals relating to the wheel speeds of the individual wheels. The function of an ABS system or of a traction control system may also be integrated into the control unit here.

The present invention seeks therefore to improve a brake-pressure control system of the type referred to in

such a way that, in an overwhelming number of braking situations which are controlled by the driver by activating the single-circuit master cylinder, the reaction force which can be felt at the brake pedal as a function of the pedal travel is a reliable measure of the anticipated value of the deceleration of the vehicle and a pedal travel/brake pressure characteristic is achieved which helps to avoid distractions relating to the operational capability of the brake system.

According to the present invention there is provided a brake-pressure control system of the type referred to, characterized by the following features:

c) the single-circuit master cylinder is such that the volume of brake fluid which can be displaced from its output pressure space as a result of displacement of its piston by the maximum stroke s_{max} is significantly greater than the capacity of the wheel brakes of the front-axle brake circuit which has to be displaced into the said brakes in order to achieve a defined design pressure necessary for a minimum deceleration;

d) the front-wheel brakes are also blocked off from the single-circuit master cylinder in the case of electrically controlled normal braking, and the maximum capacity of the output pressure spaces of the brake-pressure servo-cylinders of the front-wheel brakes is limited to that volume which has to be capable of being displaced into the respectively connected wheel brake in order to achieve a maximum brake pressure;

e) a storage element, into which brake fluid can be displaced from the single-circuit master cylinder counter to an increasing reaction force, is connected to the pressure outlet of the single-circuit master cylinder of the desired-value setting unit the maximum capacity of this storage element corresponding at maximum to the additional amount by which the volume of brake fluid which can be displaced from the master cylinder is greater than the volume of brake fluid

which can be displaced into the front-wheel brakes in emergency operating mode in order to achieve the defined minimum deceleration.

Accordingly, the single-circuit master cylinder is dimensioned in such a way that the volume of brake fluid which can be displaced in total from the output pressure space of the master cylinder by displacing the piston of the said master cylinder by the maximum stroke s_{max} which can be prescribed by physical means is significantly, preferably by a defined fraction, greater than the volume of that quantity of brake fluid which has to be displaced into the front-wheel brakes in order to achieve in the said brakes a defined brake pressure which is provided for emergency braking situations according to the design of the brakes. In combination with this, there is furthermore provision that, also in the case of electrically controlled normal braking, the front-wheel brakes are blocked off from the single-circuit master cylinder - by actuation of the change-over valves - i.e. the build-up in brake pressure takes place solely by activation of the brake-pressure servo-cylinders so that it is possible, as further provided, for the maximum capacity of the output pressure spaces of the brake-pressure servo-cylinders to be limited to that volume which has to be capable of being displaced into the respectively connected wheel brake in order to achieve a maximum brake pressure in the said wheel brake, which corresponds to a lowest possible spatial requirement of the brake-pressure servo-cylinders.

Furthermore, a storage element is connected to the pressure outlet of the single-circuit master cylinder of the desired-value setting unit, into which storage element brake fluid can be displaced counter to an increasing reaction force by activating the single-circuit master cylinder, so that a displacement of the master cylinder piston, and thus an ergonomically favourable travel/force characteristic curve of the brake-pressure control device can be attained even if the front-wheel brakes are blocked off from the single-circuit master cylinder. Finally, in combination with

this, there is provision for the maximum capacity of the storage element to correspond to at maximum the additional amount by which the volume of brake fluid which can be displaced from the master cylinder is greater than the capacity of the front-wheel brakes which is necessary in emergency braking situations to achieve a defined minimum deceleration, as a result of which it is ensured that, in an emergency braking mode of the brake-pressure control device which has to be possible even in the event of a failure of the vehicle's electrical system, a build-up in brake pressure which is necessary for a sufficient deceleration of the vehicle of e.g. 0.4 g remains possible solely by activating the single-circuit master cylinder.

A favourable relation between pedal travel in the emergency braking mode and capability of metering in the normal braking mode is obtained if the maximum capacity of the storage element is between 30 and 60%, preferably about 50%, of the volume of brake fluid which can be displaced in total into the front-wheel brakes.

A storage element which is suitable for these relations can be easily realized as a piston-spring storage means.

In particular for the emergency braking mode of the brake-pressure control device, it is advantageous if the storage element can be blocked off from the single-circuit master cylinder so that the entire volume of brake fluid which can be displaced therefrom is available for building up the brake pressure in the front-wheel brakes.

It is easily possible to block off the storage element from the master cylinder automatically, with any desired design of the storage element, in the event of a failure of the vehicle's electrical system by connecting a solenoid valve between the said storage element and the master cylinder, the excited position of the said solenoid valve being its flow position and its normal position - which is spring-centred - being its blocking position.

Provided that the storage element is constructed

as a piston-spring storage means in which the storage spring is arranged in a spring chamber which is filled with brake fluid and can be connected in a communicating fashion to the brake-fluid reservoir vessel, a functionally corresponding solenoid valve can be connected between the said reservoir vessel and the spring chamber.

As an alternative to a "passive" piston-spring storage means, a hydraulic cylinder which can be driven by electric motor and has a piston whose position is monitored may be provided as storage element, the drive of the said cylinder preferably not being self-locking but instead provided with a mechanical arresting brake which is automatically active in the de-energized case. With such a storage element, in principle any desired pedal travel/reaction force characteristic curves can be obtained by means of appropriate electrical actuation of the drive, and it is also possible, in the case of anti-lock braking control, to initiate a reaction behaviour of the master cylinder which signals the activation of anti-lock braking control to the driver in an intelligible fashion.

So that excessively large pedal activation travels do not have to be tolerated in emergency braking mode, it is particularly advantageous if, for the emergency braking mode, the single-circuit master cylinder can be adjusted to a ratio of its displacement volume related to the piston stroke which is increased in comparison with the normal braking mode, it being particularly expedient for safety reasons if the master cylinder can be adjusted automatically, for example with path control, to the displacement volume/stroke ratio which is increased for the emergency braking mode.

By virtue of the features of Claims 11 and 12 on the one hand and the features of Claims 14 to 16 on the other, alternative designs of the single-circuit master cylinder which are suitable for this are disclosed, the said designs enabling the activation, in each case after a minimum stroke of the master cylinder piston which can be

activated by means of the brak pedal, of an additional piston face and as a result increasing the volume of brake fluid which can be displaced from the master cylinder per unit of the stroke.

The design of the master cylinder according to Claim 16 is particularly advantageous in this context, in which design a steady transition of the force/travel relation, which is decisive for the normal braking mode, to the force/travel relation which is valid in the emergency braking mode can be achieved by means of appropriate matching of a spring, which acts between two piston elements, to the reaction force which is conditioned by the brake pressure.

Further details of the brake-pressure control system according to the invention emerge from the following description of exemplary embodiments with reference to the drawing, in which:

Fig. 1 shows a schematically simplified block diagram of an electrohydraulic brake system having a brake-pressure control device, which is equipped, for pedal-travel simulation, with a storage element which is constructed as a piston-spring storage means,

Figs. 2a and 2b each show, in a view corresponding to Fig. 1, a further exemplary embodiment of a brake-pressure control device which can be used in the brake system according to Fig. 1, and

Figs. 3a and 3b show alternative designs in each case of one single-circuit master cylinder which can be used as a brake-pressure transmitter unit in the brake-pressure control device, each in a schematically simplified longitudinal-sectional view.

The brake system which is designated in its entirety by 10 in Fig. 1, for a road vehicle which is represented thereby and for which it may be assumed, simply for the purpose of explanation, that it has a rear-axle

drive, comprises four brake-pressure actuators 16 and 17 and 18 and 19 which are each individually assigned to the front-wheel brakes 11 and 12 and the rear-wheel brakes 13 and 14 and can be actuated by means of a brake-pressure control device which can be activated by the driver and is designated in its entirety by 21, in order to generate brake pressures which can be applied to the wheel brakes 11 to 14.

The brake-pressure actuators 16 to 19 are, in terms of their basic design, constructed as hydraulic linear cylinders which each have an output pressure space 22 which is connected in each case to one of the front-wheel brakes 11 and 12 or the rear-wheel brakes 13 and 14 and is delimited on one side in a movable fashion by a piston 23 which is displaceably guided in the cylinder casing in a pressure-tight fashion, by means of the displacement of which piston 23, in the sense of reducing the volume of the output pressure space 22, brake fluid can be forced into the respectively connected wheel brake and as a result brake pressure can be built up, and as a result of the displacement of which piston 23, in the sense of increasing the volume of the respective output pressure space 22, brake pressure can be reduced in the respectively connected wheel brake.

For driving the pistons 23 of the brake-pressure actuators 16 to 19 in this respect, the said actuators 16 to 19 are provided with electromotive linear drives 24 which can be actuated by means of output signals of an electronic control unit 26 of the brake-pressure control device 21 in order to drive the pistons 23 in their alternative directions of movement. Such linear drives which have an electric motor 27 with reversible direction of rotation and a schematically indicated gear mechanism 28, which enables unambiguously correlated translation of the rotational movements of the armature of the electric motor 27 into the reciprocating movements of the piston 22 by means of positive engagement of driving and driven elements, are expediently constructed as spindle drives whose drive

spindles or spindle nuts which engage with the piston 23 are driven by means of spur gearing which, being capable of being switched to alternative directions of rotation, can provide different transmission ratios, in particular such that a greater transmission ratio is effective in the case of the pressure-reducing stroke of the piston 23 than in the displacement stroke which leads to the building up of brake pressure in the connected wheel brake.

The brake-pressure control device 21 comprises, as a control unit, by means of whose activation the driver can determine the magnitude of a desired vehicle deceleration, a "rudimentary" single-circuit master cylinder 31 which can be activated by means of a brake pedal 29, has only one pressure outlet 32 and can be activated "directly", without the customary intermediate connection of a brake booster, but otherwise corresponds structurally to a customary static master cylinder.

Connected to this - single - pressure outlet 32 of the master cylinder 31 is a master brake line 33 which branches at a branch point 34 into two brake line branches 36 and 37 which each lead to one of the two front-wheel brakes 11 and 12 and are connected directly thereto in each case, as a result of which the two front-wheel brakes 11 and 12 of the vehicle are combined to form a front-axle brake circuit I. The two brake line branches 36 and 37 can be blocked off, individually or together, from the master brake line 33 by means of one change-over valve 38 or 39 in each case. The change-over valves 38 and 39 are constructed as 2/2-way solenoid valves which can in turn be actuated by means of output signals of the electronic control unit 26 of the brake-pressure control device 21 and whose normal position 0, assumed in the non-excited state of their control magnets 41, is a flow position which connects the respective front-wheel brake 11 or 12 to the master brake line 33, and whose switched position I, assumed in the excited state of the control magnet 41, is a blocking position in which the front-wheel brake or brakes 11 and/or

12 is/are blocked off from the master brake line 33 and the pressure outlet 32 of the master cylinder 31.

Assuming a fault-free state of the brake system 10, the change-over valves 38 and 39 are switched over into the blocking position I whenever the respectively connected wheel brake or brakes 11 and/or 12 is/are activated, irrespective of whether activation is controlled by the driver or is triggered automatically, for example for the purpose of vehicle movement control.

In contrast with the brake-pressure actuators 16 and 17 which are provided for the front-wheel brakes 11 and 12 and whose output pressure spaces 22 are connected, in a communicating fashion, to the pressure outlet 32 of the single-circuit master cylinder 31 of the brake-pressure control device 21 in the normal positions 0 of the change-over valves 38 and 39, and in the non-activated state of the said single-circuit master cylinder 31 are connected, in a communicating fashion, to the brake-fluid reservoir vessel 42 of the said master cylinder 31, as a result of which the required volume-equalizing flows are possible, the brake-pressure actuators 18 and 19 of the rear-wheel brakes 13 and 14 are constructed in the manner of single-circuit master cylinders whose pressure output spaces which are permanently connected to the rear-wheel brakes 13 and 14 can be connected "directly" to the brake-fluid reservoir vessel 42 of the single-circuit master cylinder 31 by means of a - common - equalizing line 43, this communicating connection of the brake-fluid reservoir vessel 42 of the brake-pressure control device 21 to the output pressure spaces 22 of the brake-pressure actuators 18 and 19 of the rear-wheel brakes 13 and 14 of the vehicle only existing if their pistons 23 are in their illustrated normal position which corresponds to the non-activated state of the brake system 10 and in which equalizing flow paths which are illustrated in schematically simplified form by means of blow holes 44 are released, the said equalizing flow paths being blocked after a short initial section of a pressure-increasing stroke of

the piston 23 of the brake-pressure actuators 18 and/or 19 of the rear-wheel brakes 13 and/or 14.

Connected between the rear-wheel brakes 13 and 14 is a pressure-equalizing valve 46 which is constructed as a 2/2-way solenoid valve, can be actuated by means of output signals of the electronic control unit and, in its flow position, assumed in the non-excited state of its control magnet 47 as normal position 0, connects the two rear-wheel brakes 13 and 14 to one another and in its switched position I, assumed when its control magnet 47 is excited with an output signal of the electronic control unit 26, blocks off the rear-wheel brakes 13 and 14 from one another, the flow position 0 of this equalizing valve 46 being assigned to a normal braking mode, controlled by the driver, of the brake system 10, while the blocking position I is assigned for example to a traction control mode of the brake system 10, which mode can require individual activation of a rear-wheel brake 13 or 14 without the driver activating the brake-pressure control device 21.

The linear drives 24 of the brake-pressure actuators 16 to 19 are expediently constructed as non-self-locking drives so that a pressure-reduction movement of the pistons 23 of these brake-pressure actuators 18 and 19 is supported by the pressure prevailing in the respectively connected wheel brake 13 and/or 14. The normal position of the respective piston 23 is marked for example by a stop effect of the same with a (not illustrated) stop element which is non-displaceable with respect to the cylinder casing.

The initial position from which a brake-pressure-increasing stroke of the respective piston 23 of the brake-pressure actuators 16 and 17 of the front-wheel brakes 11 and 12 must be possible, which stroke permits a maximum brake pressure to be developed in the respectively connected wheel brake 11 or 12, which pressure permits, even in the case of a dry road with good grip, the locking limit of the respective wheel brake 11 or 12 to be reached, corresponds

to the maximum volume of the output pressure space 22 of the brake-pressure actuators 16 and 17.

The same applies correspondingly to the normal position of the pistons 23 and of the brake-pressure actuators 18 and 19 of the rear-wheel brakes 13 and 14.

The brake-pressure control device 21 comprises an electronic or electromechanical pressure sensor 48 which is connected to the master brake line 33 or the pressure outlet 32 of the single-circuit master cylinder 31 and generates an electrical output signal which is fed to the electronic control unit 26 as information input and which is a measure of the output pressure of the single-circuit master cylinder 31 which is generated by activation of the said master cylinder 31. This output signal of the pressure sensor 48 can be used in the normal braking mode of the brake system 10 as a desired-value setting signal for the brake pressure which is to be applied to the front-axle brake circuit I, and the said output signal is fed to the electronic control unit 26.

Furthermore, the brake-pressure control device comprises an electronic or electromechanical pedal-position transmitter 49 which generates electrical output signals which contain the information on how far the brake pedal 29 is deflected from its position of rest assigned to the non-activated state of the brake system 10, it being possible, by means of the output signals of this pedal-position transmitter 49, also to detect those positions of the brake pedal 29 which the said brake pedal 29 assumes between its normal position and that position in which the customarily provided brake light switch 51 of the brake system 10 responds.

The single-circuit master cylinder 31 of the brake-pressure control device 21 is designed in such a way that the volume of brake fluid which can be displaced into the front-axle brake circuit I solely as a result of the activation of the said master cylinder 31 by means of the brake pedal 29 is sufficient to attain a defined minimum

brake pressure in the wheel brakes 11 and 12 of the front-axle brake circuit I, which brake pressure is sufficient to achieve a defined minimum deceleration of the vehicle.

Furthermore, the brake-pressure control device 21 comprises a pressure accumulator 52 which is illustrated as a piston-spring storage means and whose storage chamber 53 can be connected via a function control valve 54 to the pressure outlet 32 of the single-circuit master cylinder 31 of the brake-pressure control device 21.

The function control valve 54 is constructed as a 2/2-way solenoid valve which, in the de-energized state of its control magnet, assumes its blocking normal position 0 in which the storage chamber 53 of the pressure accumulator 52 is blocked off from the pressure outlet 32 of the single-circuit master cylinder 31 of the brake-pressure control device 21 and, when its control magnet 56 is excited with an output signal of the electronic control unit 26, it goes into a flow position I as a switched position in which the pressure outlet 32 of the single-circuit master cylinder 31 is connected in a communicating fashion to the storage chamber 53 of the pressure accumulator 52.

The pressure accumulator 52 is designed in such a way that the maximum capacity of its storage chamber 53 corresponds approximately to half the value of the volume of brake fluid which can be displaced from the output pressure space (not illustrated) of the single-circuit master cylinder 31 as a result of an activation of the said master cylinder 31 corresponding to the maximum pedal travel. To this end for example the storage spring 57 against whose increasing restoring force the piston 58 can be displaced in the sense of increasing the volume of the storage chamber 53 is constructed in such a way that its turns, assuming that the restoring spring 57 is constructed as a helical spring, lie on a block, limiting the stroke of the piston, and in this limit position of the piston 58 and of its storage spring 57, the prestressing of the said spring 57 corresponds to the force which results from applying to the

storage piston 58 that pressure which has to be capable of being built up in the front-wheel brakes 11 and 12 solely by activating the master cylinder 31.

The brake-pressure actuators 16 to 19 which are individually assigned to the wheel brakes 11 to 14 are provided with in each case one electronic or electromechanical position transmitter 59 which generates an electrical output signal which, in terms of level and/or frequency, is a measure of the position of the piston 23 within the respective actuator casing and is thus also an accurate measure of the volume of the output pressure space 22 of the respective brake-pressure actuator 16 to 19.

Furthermore, connected to at least one of the front-wheel brakes 11 and/or 12 and also to at least one of the rear-wheel brakes 13 and/or 14 is an electronic or electromechanical pressure sensor 61 which generates an electrical output signal which is fed to the electronic control unit 26 and, in terms of level and/or frequency, is a measure of the brake pressure p_{VA} and p_{HA} which is applied to the respectively connected wheel brake 11 and/or 12 or 14 and/or 13.

With the design of the brake system 10 explained to this extent, the following functions can be implemented in the said brake system 10, the intention being that the following explanation will also provide an adequate description of the electronic circuitry design of the electronic control unit 26 which controls these functions, which control unit 26 can be realized, given knowledge of its purpose, by a person skilled in the art of electronic circuitry, using contemporary technical means:

a) Normal braking, if appropriate including electronically controlled front-axle/rear-axle braking force distribution (EDKV):

In the case of normal braking, in which the development of brake pressure is controlled by the driver by activating the single-circuit master cylinder 31, the

change-over valves 38 and 39 of the front-axle brake circuit I are switched over into their blocking position I and the function control valve 54 is switched over into its flow position I, so that brake fluid can be displaced from the master cylinder 31 only into the storage chamber 53 of the pressure accumulator 52. The build-up of brake pressure in the wheel brakes 11 and 12 takes place exclusively by means of the brake-pressure actuators 16 and 17.

Starting from the response of the brake light switch 51, the brake-pressure actuators 18 and 19 which are assigned to the rear-wheel brakes 13 and 14 are also actuated in the sense of building up the brake pressure, the output pressure p_{HA} of the said rear-wheel brakes 13 and 14, which output pressure p_{HA} can be monitored by means of the pressure sensor 61 assigned to the right-hand rear-wheel brake 14, when the equalizing valve 46 is open, being adjusted in accordance with the output pressure, which can be detected by means of the pressure sensor 48, of the single-circuit master cylinder 31 and/or the brake pressure p_{VA} which is detected by means of the pressure sensor 61 of the front-axle brake circuit I, in such a way that a desired, for example the ideal, distribution of braking force which corresponds to identical utilization of adhesion at the front wheels and at the rear wheels is obtained.

b) Anti-lock braking control (ABS function):

If a tendency to lock occurs at one of the front wheels of the vehicle, the associated brake-pressure actuator 16 or 17 is actuated in the sense of reducing brake pressure in the wheel brake. The brake-pressure holding function is achieved by deactivating the respective actuator drive 24.

For anti-lock braking control at the rear-wheel brakes 13 and 14, the brake-pressure actuators 18 and 19 of the wheel brakes 13 and 14 are preferably actuated together in the sense of increasing the volume of their output pressure spaces 22. Moreover, the control of phases for

holding the brake pressure and phases for building the brake pressure up again at the rear-wheel brakes 13 and 14 takes place in a fashion which is analogous to that at the front-wheel brakes 11 and 12 according to known criteria of brake slip control.

c) Traction control (TCS function):

The activation of one or both wheel brakes 13 and 14 of the driven vehicle wheels which is necessary for this without the intervention of the driver is possible as a result of the respective brake-pressure actuator 18 and/or 19 being actuated in a brake pressure-increasing fashion, the same applying to reducing the brake pressure again, in which case, in TCS mode, the equalizing valve 46 is moved into its blocking position I.

d) Automatic activation of the wheel brake of a non-driven vehicle wheel for the purpose of vehicle movement control (VMC):

For individual or common activation of the front-wheel brake or brakes 11 and/or 12, the latter is/are blocked off from the single-circuit master cylinder 31 by driving the respective change-over valve 38 and/or 39 into its/their blocking position I and the brake-pressure actuator or actuators 16 and/or 17 is/are adjusted to its/their brake-pressure control mode which is in turn accomplished according to known criteria of vehicle movement control.

Owing to the possibility of automatic activation of all the wheel brakes 11 to 14, the brake system 10 also fulfils the conditions for vehicle spacing control in the case of backed-up traffic, a vehicle spacing sensor system (not illustrated) on the vehicle having to be additionally provided for this.

e) Automatic full braking (brake boosting function):

Utilizing the brake-pressure actuators 16 to 19

provided for the automatic activation of the wheel brakes 11 to 14, automatic control of full braking is also possibl , the said full braking being triggered when the electronic control unit 26 "detects", from the manner in which the driver activates the brake pedal, that braking with the greatest possible degree of deceleration of the vehicle is desired. In this case, the brake-pressure actuators 16 and 17 of the front-axle brake circuit I and the brake-pressure actuators 18 and 19 of the rear-wheel brakes 13 and 14 are actuated in the sense of building up the brake pressure with a maximum rate of increase in the brake pressure. The triggering of such full braking expediently takes place when the speed $\dot{\phi}$, which can be monitored by means of the pedal position transmitter 49 and at which the driver activates the brake pedal 29, exceeds a threshold value $\dot{\phi}_S$. Such full braking is continued for as long as the driver activates the brake pedal 29 with increasing force, the development of which over time can be detected for example by means of the output signals of the pressure sensor 48 which detects the output pressure of the single-circuit master cylinder 31. Continuation of this braking with a reduced rate of increase in the brake pressure can be triggered in that the driver adjusts the brake pedal in accordance with the development of brake pressure but activates the brake pedal with only a relatively small force. The full braking is aborted if the driver releases the brake pedal 29.

The purpose of the brake-pressure control device 21 of the brake system 10 is to achieve, in cases in which the development of brake pressure is controlled by the driver, i.e. in the case of normal braking, but also in the case of full braking, ergonomically favourable relations between the pedal travel and the braking force-deceleration of the vehicle - which is actually developed, which braking force can then be best metered, in a fashion appropriate for the situation, if a sufficiently large degree of pedal deflection travel is also combined with a high degree of deceleration of the vehicle. In the case of the brake-

pressure control device 21, this pedal travel is made available to a sufficient degree by the pressure accumulator 52, which acts, as it were, as a travel simulator, but at the same time this pedal travel is limited to a value which ensures that, in the event of a failure of the brake-pressure actuators 16 to 19 of the front-axle brake circuit I and of the rear-wheel brakes 13 and 14, a sufficient development of brake pressure, which permits sufficient minimum deceleration of the vehicle to be obtained, is still possible solely by activating the single-circuit master cylinder 31 in the front-axle brake circuit.

In such an emergency situation, which can be brought about for example by a failure of the vehicle's electrical system, the front-axle brake circuit remains operational, since the change-over valves 38 and 39 drop back into their normal position 0 connecting the wheel brakes 11 and 12 to the pressure outlet 32 of the master cylinder 31, so that as a result of the activation of the said master cylinder 31, brake pressure can be built up in the front-wheel brakes 11 and 12. At the same time, the function control valve 54 is switched back into its blocking normal position and, as a result, the pressure accumulator 52 is blocked off from the single-circuit master cylinder, the entire volume of whose brake fluid is now available for building up brake pressure in the front-axle brake circuit.

The desired-value setting unit which, in the exemplary embodiment in accordance with Fig. 1, comprises the single-circuit master cylinder 31, the pressure accumulator 52 and the function control valve 54, is designated in its entirety by 62 and, in the case of a failed vehicle electrical system, also permits an emergency braking mode of the front-axle brake circuit, can be modified (not illustrated separately) in such a way that the storage chamber 53 of the pressure accumulator 52 is connected in a permanently communicating fashion to the pressure outlet 52 of the single-circuit master cylinder 31. For this design of the brake-pressure control device 21, its

single-circuit master cylinder 31 is to be configured in such a way that th volume of brake fluid which can be displaced from the said master cylinder 31 is at least the maximum capacity of the front-wheel brakes 11 and 12 plus the absorption capacity of the pressure accumulator 52.

In order to explain further variants of the desired-value setting unit 62 of the brake-pressure control device 21, reference will now be made to Figs. 2a and 2b, in which in each case the part of the brake system 10 which is required for the emergency braking mode is illustrated.

The desired-value setting unit 62′ according to Fig. 2a is functionally analogous to the desired-value setting unit 62 according to Fig. 1 and differs therefrom in structural terms only in that the storage chamber 53 of the piston-spring storage means 52 which is used for pedal travel simulation is connected directly to the master brake line 33 starting from the single-circuit master cylinder, and furthermore in that the spring space 63 of the pressure accumulator 53′ in which the storage spring 57 is arranged is of fluid-tight construction and is filled with brake fluid, and in that the function control valve 54 is connected between the spring space 63 of the pressure accumulator 52′ and the pressureless brake-fluid reservoir vessel 42 of the single-circuit master cylinder 31. In this design of the desired-value setting unit 62′, the piston 58 of its pressure accumulator 52′ can be locked in its minimum capacity of the storage chamber 53 in that the function control valve 54 prevents, in its blocking normal position 0, brake fluid overflowing from the spring space 63 into the reservoir vessel 42. With the desired-value setting unit 62′ in accordance with Fig. 2a, brake fluid losses due to leakage are largely ruled out.

The desired-value setting unit 62′′ (illustrated in Fig. 2b), which can also be used in the brake system 10 in accordance with Fig. 1, differs in structural terms from that described with reference to Figs. 1 and 2a in that, in order to achieve a desired pedal travel/output pressure

characteristic of the single-circuit master cylinder 31, instead of a pressure accumulator 52 or 52′ and a function control valve 54, a volume actuator 64 is provided which can be controlled electrically by means of output signals of the electronic control unit 26 and is constructed in a fashion which is structurally analogous to the brake-pressure actuators 16 and 17 of the front-axle brake circuit I, as a hydraulic linear cylinder. This linear cylinder has an output pressure space 66 which is connected to the master brake line 33 of the brake-pressure control device 21 and is delimited on one side in a movable fashion by a piston 67 which is displaceably guided in the cylinder casing in a pressure-tight fashion and which can be displaced in alternative deflection directions by means of an electromotive linear drive 68, it being possible for this electromotive linear drive 68 to be actuated by means of output signals of the electronic control unit 26 in order to drive the piston 67 in its alternative directions of movement. This electromotive linear drive is constructed as a non-self-locking drive, which is analogous to the electromotive linear drives of the brake-pressure actuators 18 and 19 for the rear-wheel brakes 13 and 14 of the vehicle. However, the said electromotive linear drive is provided with a brake 69 which is indicated schematically by means of two brake blocks and can be released electrically under the control of an output signal of the electronic control unit 26 and, if the release signal of the electronic control unit 26 is lost, moves automatically, for example as a result of the prestressing of a brake spring (not illustrated), into its brake position which secures the rotor of the electric drive motor 71. The electromotive linear drive 68 of the volume actuator 64 is provided with an electromechanical or electronic position transmitter, which generates an electrical output signal which is fed to the electronic control unit 26 and is a measure of the position of the piston 67 of the volume actuator 64 within its cylinder casing 73, and thus also a measure of the

volume of the output pressure space 66 of the volume actuator 64.

The desired-value setting unit 62'' according to Fig. 2b provides, when used in a brake-pressure control device 21 in accordance with Fig. 1, at least the following control possibilities, the intention being that the explanation of these control possibilities will also explain the relevant modification of the circuitry of the electronic control unit 26, which modification the person skilled in the art can realize, given knowledge of the purpose of the control, on the basis of contemporary specialist knowledge.

a) Storage function:

The volume actuator 64 can be actuated, as a function of output signals of the pedal position transmitter 49 and/or the pressure sensor 48 of the desired-value setting unit 62'' in combination with the output signals of the position transmitter 72 of the volume actuator 64, in such a way that its function is analogous to that of the pressure accumulators 52 or 52' of the embodiment variants according to Fig. 1 or 2a, i.e. in the case of normal braking the volume of the output pressure space 66 of the volume actuator 64 rises increasingly as the activation force with which the driver activates the brake pedal 29 increases.

b) Displaying an anti-lock braking control function:

If a tendency to lock occurs during braking, controlled by the driver, at one of the wheels of the vehicle, and has to be corrected, the volume actuator is actuated in the sense of reducing the volume of its output pressure space 66, with the result that the brake pedal 29 is pushed back counter to the activation force applied by the driver, which signals to the driver in an intelligible fashion that the braking situation is potentially hazardous.

The volume actuator 64 can, in principle, be used to realize any desired pedal-travel/brake-pressure

characteristics of the desired-value setting unit 62, which can be prescribed in the sense of optimized programming depending on the speed range in which the vehicle is moving and/or the magnitude of the deceleration of the vehicle which is to be determined by activating the brake pedal 29.

In order to explain possible designs of the single-circuit master cylinder 31 which is provided in the brake-pressure control device 21, reference will now be made to Figs. 3a and 3b.

The casing 74 of the single-circuit master cylinder 31 illustrated in Fig. 3a has two hole steps 77 and 78 which are coaxial with respect to the central longitudinal axis 76 of the said master cylinder 31 and have different diameters D1 and D2, between which diameters a radial inner shoulder 79 of the casing 74 runs and via which these hole steps 77 and 78 adjoin one another. The piston 81, which is designed in one piece, is guided so as to be displaceable in a pressure-tight fashion with a flange-shaped piston step 82 in the hole step 77 with the larger diameter D1 and with a rod-shaped piston step 83 in the hole step 78 with the smaller diameter D2 of the cylinder casing 74. The pedal plunger 84 via which the activation force is transmitted to the cylinder piston 81 acts on the rod-shaped piston step 43. Within the hole step 77, the flange-shaped piston step 82 forms, on the one hand, the axially movable delimitation of the output pressure space 86 of the master cylinder 31 on one side and, on the other hand, the one, axially movable delimitation of an annular space 85 whose second axial delimitation, which is fixed to the casing, is formed by the radial inner shoulder 79 of the casing 74. In the pedal-end region of the cylinder casing 74 which is adjacent to the annular shoulder 79 of the casing, the said casing 74 is provided with an annular groove 87 which opens into the casing hole 78 with the smaller diameter D2 and forms a run-on and equalizing space which has a continuously communicating connection to the brake-fluid reservoir vessel 42 via a radial passage 88. The piston 81 is forced, by

means of a restoring spring 89 which acts on its flange-shaped piston step 82 and is supported on the end wall 91 of the casing 74 which forms the axial delimitation, fixed to the casing, of the output pressure space 86, into its illustrated normal position which corresponds to the maximum volume of the output pressure space 96 and the minimum volume of the annular space 85 and in which the cylinder piston 81 is axially supported with the pedal-end free end face 92 of its rod-shaped piston step 83 on an annular stop shoulder 93 of the casing 74.

The piston 81 is provided with a central valve which is designated in its entirety by reference 94 and, in the illustrated normal position of the piston 81 of the single-circuit master cylinder 31 which corresponds to the non-activated state of the said master cylinder 31, assumes an open position in which a central axial equalizing passage 96, which has a permanently communicating connection to the annular space 85 of the single-circuit master cylinder 31 via a radial overflow passage 97, is connected in a communicating fashion to the output pressure space 86 of the master cylinder 31, the equalizing passage 96 being also connected, in the illustrated normal position of the piston 81 of the single-circuit master cylinder 31, to the annular groove 87 of the cylinder casing 74 in a communicating fashion, via a radial blow hole 98.

When the master cylinder 31 is activated, this communicating connection of its annular groove 87, which is arranged between annular seals 99 and 101 which are fixed to the casing, is eliminated after a small part of the overall possible pressure-increasing stroke, after which, if the central valve 94 is still open, the communicating connection of the annular space 85 to the output pressure space 86 of the master cylinder 31 still initially exists. In the further course of a brake-pressure-increasing stroke, the central valve 94 initially remains open, with the result that only a part m_{S1} of the quantity m_S of brake fluid which is displaced in its entirety from the output pressure space

86 of the single-circuit master cylinder 31 when pressure-increasing activation of the said master cylinder 31 takes place is displaced via the pressure outlet 32 of the master cylinder 31 to the front-wheel brakes 11 and 12, while the complementary partial quantity m_{s2} is absorbed from the annular space 85 of the master cylinder 31 via the open central valve 34, the ratio m_{s1}/m_{s2} being given by the relation

$$m_{s1} / m_{s2} = D2^2 / (D_1^2 - D2^2)$$

This ratio can be prescribed in a defined fashion by appropriate selection of the diameters D1 and D2 of the casing holes 77 and 78 and of the diameters of the piston sections 82 and 83 of the master cylinder piston 81 of the master cylinder 31. In a departure from the schematic illustration selected for explanation, the said ratio has a value of about 1.

In the illustrated, specific exemplary embodiment, the central valve 94 is designed in such a way that, after the piston 81 has executed half of its maximum possible pressure-increasing stroke smax when a brake-pressure-increasing activation of the master cylinder 31 takes place, the said central valve 94 moves into a closed position in which the communicating connection of the output pressure space 86 to the annular space 85 of the master cylinder 31 is eliminated, with the result that, when there is a further brake-pressure-increasing activation of the master cylinder 31 and when the displacement of the master cylinder piston 81, which is correlated therewith, in the sense of reducing the volume of the output pressure space 86 takes place, the quantity M_s of brake fluid which is displaced therefrom in total and is related to the unit of the piston stroke is now used to build up brake pressure in the front-wheel brakes 11 and 12 of the brake system 10. The master cylinder 31 is thus switched over, in a travel-dependent fashion, to a larger displacement volume per unit of the activation travel

of the brake pedal 29. This function state of the master cylinder 31 is assigned to the emergency braking mode which, when the vehicle's electrical system has failed, still ensures that a minimum braking deceleration is achieved.

The central valve 94, which in combination with the explained design of the casing 74 and of the piston 81 of the single-circuit master cylinder 31 enables the said master cylinder 31 to be switched over to increasing, in accordance with demand, the quantity of brake fluid which can be used in the emergency braking mode for building up brake pressure, is constructed in the specific exemplary embodiment illustrated as a ball-seat valve whose valve ball 102 is arranged in an axially displaceable fashion in a hole 103 which is coaxial with the central equalizing passage 96 and has a relatively large diameter, which may also be slightly larger than that of the valve ball 102, and the said valve ball 102 can be forced by a valve spring 104 into a position of maximum distance from a conical valve seat 106 which runs between the hole 103, in which the valve ball is arranged so as to be displaceable backwards and forwards, and an axially short hole step 107 at whose base, from which the central equalizing passage 96 starts, the valve spring 103 is supported at the piston end.

The maximum distance between the valve ball 102 and its valve seat 106 is marked by its bearing against a drive pressure space-end stop element 108 which is inserted into the receiving hole 103 and is provided with azimuthal cutouts via which the output pressure space 86 of the master cylinder 31 remains in continuously communicating connection with the guide hole 103 of the valve ball 102. Arranged within the output pressure space 86 is a stop plunger 109 which is coaxial with the central longitudinal axis 76 of the single-circuit master cylinder 31 and is forced, by a prestressed helical compression spring 111, into a position which is marked by a stop effect of a flange-shaped stop element 112 of the stop plunger 109 with an annular stop element 114 of a guide pipe 113, is illustrated in Fig. 3a

and in which its free end face 116 is, viewed in the illustrated normal position of the master cylinder piston 81, at an axial distance s_a from the valve ball 102 which is significantly smaller than half the maximum piston stroke s_{max} by which the master cylinder piston 81 can be displaced between its illustrated normal position and a limit position which corresponds to the minimum volume of its output pressure space 86 and is expediently marked by the block position of the turns of the restoring spring 89, by means of whose prestressing the master cylinder piston 81 can move back into its normal position when the brake pedal 29 is released.

The prestressing of the helical compression spring 111 which forces the stop plunger 109 into its illustrated "normal" position is greater than the axial prestressing of the valve spring 104 which is obtained in the closed state of the central valve 94 in which its valve ball bears against the valve seat 196 in a sealing fashion.

In turn, the axial distance s_{as} of the valve ball 102 from its seat 106 has, viewed in the illustrated normal position of the master cylinder piston 81, a value which itself is significantly smaller than half the value of the maximum pressure-increasing stroke s_{max} of the master cylinder piston 81, the sum of the distance values $s_{as} + s_a$ corresponding to half the maximum displacement stroke s_{max} of the master cylinder piston 81.

The helical compression spring 111 which forces the stop plunger 109 into its illustrated position which corresponds to the maximum distance of its free end face 116 from the end wall 91 of the cylinder casing 74 is dimensioned in such a way that it can be compressed, shortened, by half the maximum stroke s_{max} of the master cylinder piston 81.

The annular space-end annular seal 101, which enables the annular groove 87 of the master cylinder casing 31 to be sealed with respect to the annular space 85, is constructed as a lip seal which enables the function of a

non-return valve which is acted on in the opening direction when there is lower pressure in the annular space 85 than in the reservoir vessel 42 of the single-circuit master cylinder 31 and is acted on in a blocking fashion when there is relatively higher pressure in the annular space 85 of the master cylinder 31 than in its reservoir vessel 42.

The single-circuit master cylinder 31 whose design is explained to this extent permits the following functions in the brake system 10 in accordance with Fig. 1:

The stroke range of the magnitude $s_{max}/2$, within which the central valve 94 of the master cylinder piston 81 remains open when the master cylinder 31 is activated by pedal, is utilized for the electronically controlled generation of brake pressure and/or control of the distribution of braking force.

The stroke of the master cylinder piston 81 which is additionally made available and within which the central valve is closed, permits, without accompanying action of the brake-pressure actuators 16 and 17 of the front-axle brake circuit, a, in relation to the piston stroke, greater quantity of brake fluid to be fed into the front-wheel brakes 11 and 12, and thus a desired minimum deceleration of the vehicle to be achieved even if all the brake-pressure actuators 16 to 19 which can be electrically controlled under normal circumstances are no longer operational.

In this emergency operating state of the master cylinder 31, the non-return valve which is formed by the annular space-end sealing ring 101 of the master cylinder 31 and via which brake fluid can now subsequently flow, in emergency operating mode, from the reservoir vessel 42 into the annular space 85 is active, although the central valve 94 assumes its blocking position.

In the single-circuit master cylinder 31 which is illustrated in Fig. 3b and which can be used in the brake system 10 according to Fig. 1, the single-side, axially movable delimitation of its output pressure space 86 is formed by a piston arrangement 117, 118 which comprises an

outer annular piston 117 and a step piston 118 which is coaxially surrounded thereby and on which the pedal plunger 84 acts, which piston arrangement 117, 118 is forced, by the restoring spring 89 which is supported on the end wall 91 of the cylinder casing 74, which end wall 91 forms the axial delimitation, fixed to the casing, of the output pressure space 86, and acts on the central, opposite end face 119 of the step piston 118, into the illustrated normal position which corresponds to the non-activated state of the master cylinder 31 and in which the annular piston 117 is axially supported with its pedal-end annular face 121 on a radially inwardly pointing stop ring 122 of the cylinder casing, and the step piston 118 is axially supported with its pedal-end end face on a radially inwardly pointing, annular stop flange 124 of the annular piston 117.

By means of two annular seals 126 and 127 which are fixed to the piston and arranged on end flanges 128 and 129 of the annular piston 117, the annular piston 117 is sealed with respect to the casing hole 77 whose diameter has the value D_1 over the entire length of the casing between its end wall and its stop ring 122. Extending between the output pressure space-end end flange 128, whose annular seal 126 provides a high-pressure-tight seal, and the pedal-end end flange 129 of the annular piston 117 is an annular space 132 which is bounded by a flat annular groove 131 of the annular piston 117 and which, independently of the piston position, is connected in a communicating fashion to the reservoir vessel 42 via a radial casing passage 133. An annular space 141 extends between the pedal-end, flange-shaped piston step 134 the step piston 118, with which piston step 134 of the step piston 118 is mounted in a sliding fluid-tight fashion in a hole step 137 with the same diameter as the annular piston 117, and a radial inner shoulder 136 of the annular piston 117 which provides the connection of the hole step 137, which receives the flange-shaped piston step 134, to the hole step 139, which receives the rod-shaped piston step 138 of the step piston 118 and

has the smaller diameter D2. The annular space 141 is connected in a communicating fashion via a radial passage 142 to the radially outer annular space 132, and also to the reservoir vessel 42 via the latter. An annular seal 143 which provides the high-pressure-tight sealing of the rod-shaped piston step 138 of the step piston 118 with respect to the hole step 139 with the same diameter as the annular piston 117 is arranged on the annular piston 117 in the direct vicinity of the radial inner shoulder 136 of the said annular piston 117.

The rod-shaped section 138 of the step piston 118 is provided with a blow passage 144 which has an axial section 146 extending over part of the length of the rod-shaped section 138 of the step piston and opening into the output pressure space 86 of the single-circuit master cylinder 31, and a radial section 147 starting from the inner end of the said axial section 146 and, in the illustrated normal position of the piston arrangement 117, 118, opening, directly next to the radial inner shoulder 136 of the annular piston 117, into the radially inner annular space 141 delimited by the said annular piston 117 and the step piston 118, so that in this normal position of the piston arrangement 117, 118 there is also a communicating connection of the output pressure space 86 to the brake fluid reservoir vessel 42. When the brake pedal 29 is activated, this communicating connection is interrupted after a small initial part of the piston stroke, the build-up of pressure in the output pressure space 86 of the single-circuit master cylinder not starting until this has occurred. Arranged in the radially inner annular space 141 is a helical compression spring 148, by means of which a desired pedal force/output pressure characteristic can be achieved.

A specific design of the helical compression spring 148 may consist in the product of its spring rate and the stroke of the step piston 118 being equal to the product of the pressure prevailing in the output pressure space 86

and the annular end face, partially delimiting the latter in a movable fashion, of the annular piston 117, when the central step piston has executed half of its maximum possible piston stroke s_{max} in the course of an activation of the brakes.

Claims

1. A brake-pressure control system of the type referred to, characterized by the following features:

c) the single-circuit master cylinder is such that the volume of brake fluid which can be displaced from its output pressure space as a result of displacement of its piston by the maximum stroke s_{max} is significantly greater than the capacity of the wheel brakes of the front-axle brake circuit which has to be displaced into the said brakes in order to achieve a defined design pressure necessary for a minimum deceleration;

d) the front-wheel brakes are also blocked off from the single-circuit master cylinder in the case of electrically controlled normal braking, and the maximum capacity of the output pressure spaces of the brake-pressure servo-cylinders of the front-wheel brakes is limited to that volume which has to be capable of being displaced into the respectively connected wheel brake in order to achieve a maximum brake pressure;

e) a storage element, into which brake fluid can be displaced from the single-circuit master cylinder counter to an increasing reaction force, is connected to the pressure outlet of the single-circuit master cylinder of the desired-value setting unit the maximum capacity of this storage element corresponding at maximum to the additional amount by which the volume of brake fluid which can be displaced from the master cylinder is greater than the volume of brake fluid which can be displaced into the front-wheel brakes in emergency operating mode in order to achieve the defined minimum deceleration.

2. A brake-pressure control system according to Claim 1, the maximum capacity of the storage element is between 30% and 60%, preferably about 50%, of the total maximum absorption volume of the front-wheel brakes (11, 12).

3. A brake-pressure control system according to Claim 1, the maximum capacity of the storage element is about 50% of the total maximum absorption volume of the front-wheel brakes.

4. A brake-pressure control system according to Claim 1, 2 or 3, wherein the storage element comprises a piston-spring storage means.

5. A brake-pressure control system according to any one of Claims 1 to 4, wherein the storage element can be blocked off from the single-circuit master cylinder.

6. A brake-pressure control system according to Claim 5, wherein a change-over valve, which is constructed as a 2-position solenoid valve and whose excited position is a flow position and whose normal position is its blocking position, is connected between the storage element and the single-circuit master cylinder.

7. A brake-pressure control system according to Claim 5, the storage element being constructed as a piston-spring storage means, wherein the storage spring of the storage element is arranged in a fluid-tight spring chamber which is connected via an equalizing line to the brake-fluid reservoir vessel of the single-circuit master cylinder, and the equalizing flow path can be blocked off by means of a change-over valve which is constructed as a 2-position solenoid valve and has the flow position as excited position and the blocking position as normal position.

8. A brake-pressure control system according to Claim 1 or 2, wherein the storage element itself is constructed as a hydraulic servo-cylinder drivable by an electric motor and has a piston whose position is monitored.

9. A brake-pressure control system according to Claim 8, wherein the piston drive is not self-locking and is provided with an arresting brake which is automatically active in the de-energized case.

10. A brake-pressure control system according to any one of Claims 1 to 9, wherein, for the emergency braking mode, the single-circuit master cylinder can be adjusted to a ratio of its displacement volume related to the stroke which is increased in comparison with the normal braking mode.

11. A brake-pressure control system according to Claim 10, wherein the single-circuit master cylinder can be adjusted, with automatic path control, to the emergency braking mode with the increased displacement volume/stroke ratio.

12. A brake-pressure control system according to Claim 11, wherein the piston of the single-circuit master cylinder comprises a step piston whose piston step which is greater in terms of diameter forms the axially movable delimitation both of the output pressure space and with an annular end face which adjoins its smaller piston step and whose magnitude is given by the difference of the cross-sectional area of the end face which delimits the output pressure space and the cross-sectional area of the face of the smaller piston step, the axially movable delimitation of an annular space, and the piston is provided with a central valve which is forced into its open position by the prestressing of a valve spring and, starting from a minimum stroke s_{min} of the piston, moves into its blocking position as the result of a stop effect of its valve body with a stop element which is elastically resilient in the axial direction, and wherein a non-return valve is connected between the annular space and the reservoir vessel and is acted on, in the blocking direction, by a relatively higher pressure in the annular space of the master cylinder than in

the reservoir vessel and is acted on in the opening direction by relatively higher pressure in the reservoir vessel than in the annular space of the single-circuit master cylinder.

13. A brake-pressure control system according to Claim 12, wherein the non-return valve is formed by an annular seal comprising a lip seal and which seals the smaller piston step of the step piston with respect to the annular space and with respect to an annular groove which is connected in communicating fashion to the reservoir vessel.

14. A brake-pressure control system according to Claim 11, wherein the single-circuit master cylinder comprises a central piston which is displaceably guided in a pressure-tight fashion in an annular piston, which is itself sealed with respect to the casing so as to be displaceable in a pressure-tight fashion, the said piston being capable of being forced, by means of a restoring spring of the master cylinder which axially penetrates the output pressure space of the said master cylinder, into its normal position corresponding to the greatest volume of the output pressure space and the brake pedal engaging on the said piston, and this central piston is provided with a flange-shaped piston step which is arranged on the pedal side and, starting from a minimum stroke s_{min} of the central piston, moves along the annular piston in the sense of a pressure-increasing stroke by virtue of its axial support on a radial inner shoulder of the said annular piston.

15. A brake-pressure control system according to Claim 14, wherein the radial inner shoulder of the annular piston and the pedal-side flange-shaped piston step of the central piston delimit a radially inner annular space in the axial direction, which annular space, on the one hand, is connected in a communicating fashion via a radial passage of the annular piston to a radially outer annular space which

itself is held in a permanently communicating connection to the reservoir vessel, and the central piston is provided with a blow passage which, in the normal position of the central piston, produces a communicating connection between the output pressure space and the annular space, which connection is eliminated after a small initial section of the pressure-increasing stroke of the central piston.

16. A brake-pressure control system according to Claim 15, wherein a prestressed compression spring, whose prestress is smaller than that of the restoring spring of the single-circuit master cylinder, is arranged in the radially inner annular space of the piston arrangement.

17. A brake-pressure control system for a road vehicle with electrohydraulic multi-circuit brake apparatus, substantially as described herein with reference to, and as illustrated in, the accompanying drawings.

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Int Cl (Ed.6): B60T 8/32, 40, 42 13/68, 74

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Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2283067 A	(Mercedes-Benz) equivalent to DE 43 35 769	
A	US 5312172	(Takeuchi) see whole document	
A	US 5302008	(Akebono) see e.g.col.4 line 67-col.5 line 16	
A	US 5246283	(General Motors) see e.g.col.2 line 31-col.3 line 36	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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